ENDNOTES

Preface

1 Much of the above description on the DSN was adapted from JPL Publication 400-326 "Goldstone Deep Space Communication Complex."

Foreword

1 NASA Management Instruction NMI 1162.1W
2 "Review of the Space Communications Program of NASA's Space Operations Mission Directorate" by the National Research Council of The National Academies, The National Academies Press, 2007.

Introduction

1 Robert Godwin, *Friendship 7: The First Flight of John Glenn. The NASA Mission Reports,* (Apogee Books, Ontario, Canada, 1999), Appendix B: Air-Ground Communications of the MA-6 Flight.
2 Alfred Rosenthal, *Vital Links* (NASA Goddard Space Flight Center, 1983), p. 196.
3 Ibid, p. 60.

4 Schneider interview from *Vital Links*.
5 Mengel interview from *Vital Links*.
6 Kraft interview from *Vital Links*.
7 Carolynne White, Goddard Space Flight Center News Release 89-2, 13 January 1989, Folder Number 8813, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
8 See Note 6.
9 Force interview.
10 Prior to the Early Bird, satellites like Echo I and Echo II were passive, giant, shiny and highly reflective balloons that could only bounce, but not control, signals from one point on Earth to another.
11 See Note 6.
12 Ibid.
13 Force interview.

Chapter 1

1 The Oxford English Dictionary references the first use of the term "missile gap" from The Economist article dated 13 June 1959: "The Air Force gets an additional $170 million to help close the 'missile gap.'" John F. Kennedy is particularly connected with the phrase as he used it frequently during the 1960 presidential election campaign to attack the Republicans for their supposed complacency on the subject of Soviet Intercontinental Ballistic Missiles. Warnings and calls to address imbalances between the armed capabilities of the two countries were not new. A "bomber gap" had exercised political concerns a few years previously. What was different about the missile gap was the fear that a distant country could now strike without warning from far away. History has shown that this so-called missile gap was in fact very real. Within three years after the death of Joseph Stalin, the Soviet Union would announce that it had an effective Intercontinental Ballistic Missile force capable of striking North America and the United States. At that time, the U.S. could only field the Army's Redstone rocket, a tactical system with a range of 200 miles.
2 Mengel interview from *Vital Links*.
3 David West Reynolds, "Apollo: The Epic Journey to the Moon" (Tehabi Books, Inc., 2002), pp. 24–25.
4 Origin of the term "WAC" is somewhat unclear and may have stood for "Without Attitude Control," referring to the fact that the simple rocket was purely ballistic, with no stabilization and guidance system. The label was probably not associated with the more well-known Women's Army Corps.
5 The first monkey launched by the United States was Albert, a rhesus monkey, who on 11 June 1948 flew to nearly 40 miles altitude on a V-2 rocket

at White Sands. However, Albert died of suffocation during the flight. It was followed by Albert II who survived the V-2 flight but died on impact on 14 June 1949. However, Albert II became the first monkey in space as his flight exceeded 400,000 feet, the theoretical boundary of the detectable atmosphere. Albert III died at 35,000 feet in an explosion of his V-2 during launch on 16 September 1949. On the last V-2 monkey flight, Albert IV died on impact on 8 December 8 1949. Albert II and Albert IV were rhesus monkeys while Albert III was a cynomolgus monkey.

6 Dave Harris email, 17 April 2006.

7 K. G. Henize, "The Baker-Nunn Satellite Tracking Camera," *Sky and Telescope*, 16, 1957: pp. 108–111.

8 A 16th magnitude object is 25 times dimmer than the faintest star visible to the naked eye. Baker-Nunn cameras were able to observe the 6-inch diameter Vanguard satellite out to an altitude of 2,400 miles.

9 Kathleen M. Mogan and Frank P. Mintz, *Keeping Track* (NASA Goddard Space Flight Center, 1992), p. 9.

10 Alfred Rosenthal, *Vital Links* (NASA Goddard Space Flight Center, 1983), pp. 22–24.

11 Cristine Russell, "Watch Ends for Sputnik Spotters," *Washington Star*, A3, 26 June 1975.

12 Optical systems suffered from limitations imposed by weather and lighting conditions. Nevertheless, they proved very useful for tracking satellites with expired or failed beacons. Also, by obtaining highly accurate readings of satellite positions, the optical sites could provide information on changing global elevations caused by alterations in Earth's crust. In fact, one of the final functions of the SAO network was to serve as a progenitor to the NASA/Goddard Laser Crustal Dynamics program.

13 Perhaps Whites Sands biggest claim to fame in the early days of the range was the detonation of the world's first atomic bomb at Trinity Site, 16 July 1945, on the north part of the range.

14 "1947 History," White Sands Missile Range Fact Sheet, *http://www.wsmr.army.mil/pao/FactSheets/1947his.htm* (accessed 16 November 2005).

15 Barnes interview from *Vital Links*.

16 Covington interview from *Vital Links*.

17 "SingleObject Tracking Radars," *http://www.wsmr.army.mil/capabilities/nr/testing/range_inst/radar/sinobj.html* (accessed 30 August 2005).

18 Constance McLaughlin Green and Milton Lomask, *Vanguard: A History* (NASA SP-4202, 1970).

19 Rosenthal, pp. 17–18.

20 Ibid.

21 Mengel interview from *Vital Links*.

22 Ibid.

23 Zale, "Fast Summary: Minitrack System," 1958, Folder Number 8800, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
24 Looney interview from *Vital Links*.
25 Rosenthal, pp. 19-20.
26 John T. Mengel and Paul Herget, "Tracking Satellites by Radio," *Scientific American,* January 1958, 198, no.1, Folder Number 8800, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
27 MOTS cameras were all implemented with a solenoid assembly that would very briefly move its 8x10 inch photographic plate against a spring load. The station timing system would pulse the solenoid in a time-coded fashion, thus allowing the satellite to be displaced against the stellar background, enabling a position versus time solution. (Dave Harris email, 4/17/06)
28 See Note 26 and Ibid. In addition to performing system calibrations, MOTS was eventually used as an optical tracking system for satellites in low-Earth orbit. When NASA prepared to launch the passive Echo 1 into orbit on 12 August 1960, it needed to modify the MOTS cameras so that they could successfully photograph it and define the orbit. While inflation of the Echo balloon took place over South Africa, the first tracking images were taken by the San Diego Minitrack station. A couple of years later, on 31 October 1962, ANNA 1B was launched. The first orbital spacecraft designed to support the combined geodetic surveying requirements of the Air Force, NASA, Navy and Army, it carried a flashing light triggered by a time code. Photographing the satellite's flashes against the stellar background allowed for long distance baselines to be measured with great precision. For this effort, the Goddard Space Flight Center worked with domestic and international universities to establish a ground network of cameras in addition to those at the existing Minitrack stations. Stations were established in Jamaica, Puerto Rico, Edinburg, Texas (at Pan American University of Texas) and Sudbury, Ontario (at Laurentian University). In addition, Kodak developed a new emulsion to effectively increase film speed for the MOTS cameras.
29 Ibid.
30 See Note 21.
31 Rosenthal, p. 21.
32 Rosenthal, p. 22.
33 See Note 24.
34 The San Diego station was actually located on Brown Field Naval Auxiliary Air Station in nearby Chula Vista. When Brown Field closed in 1960, the station was moved to Mojave (soon known as Goldstone).
35 Mogan and Mintz, pp. 6–8.

36 McKeehan interview from *Vital Links*.
37 Ibid.
38 Ibid.
39 Rosenthal, p. 29.
40 Constance McLaughlin Green and Milton Lomask, *Vanguard: A History* (National Aeronautics and Space Administration Special Publication-4202, 1969).
41 Throughout most of Project Vanguard, another high-speed computer was used. An IBM 709 was installed at Patrick Air Force Base near Cape Canaveral. During launch and ascent, the vehicle was tracked using radar. After third stage burnout, the radar track data was processed by the IBM 709 and sent via teletype to the NRL Computing Center in Washington, DC. This preliminary data provided a best estimate of position and velocity at booster burnout from which the preliminary orbit determination was sent by teletype to the Minitrack stations enabling them to initialize their observation of the satellite passes.
42 See Note 26.
43 See Note 24.
44 Ibid.
45 Organization for Civil Space Programs, Memorandum for the President, 5 March 1958, Executive Office of the President, President's Advisory Committee on Government Organization, Eisenhower Library.
46 The NACA Director was selected by its 17-member governing committee.
47 See Note 45.
48 Ibid.
49 Ibid.
50 "The National Aeronautics and Space Administration: U.S. Centennial of Flight Commission," *http://www.centennialofflight.gov/essay/Evolution_of_Technology/NASA/Tech2.htm* (accessed 01 September 2005).

Chapter 2

1 JPL was transferred to NASA in 1958. It was staffed and operated by the California Institute of Technology under contract to NASA, an arrangement that continues to this day.
2 Jane Van Nimmen, Leonard C. Bruno and Robert L. Rosholt, *NASA Historical Data Book Volume I: NASA Resources 1958-1968* (National Aeronautics and Space Administration Special Publication-4012, 1988), pp. 4–5.
3 Weingarten interview from *Vital Links*.
4 Ibid.

5 Bodin interview from *Keeping Track*.
6 Nimmen, Bruno and Rosholt, pp. 309–311.
7 Dave Harris email, 16 March 2006.
8 Mengel interview from *Vital Links*.
9 Spearing interview.
10 Dunseith interview *Vital Links*.
11 At 59 missions, the Explorer series of satellites would go on to become the most successful series of science satellites ever, finally ending with Explorer 59 (the Solar Mesosphere Explorer) launched on 6 October 1981.
12 Looney interview from *Vital Links*.
13 Ibid.
14 Dave Harris email.
15 STADAN performed one other major function not covered by the acronym: satellite command, where vehicle control instructions were uplinked to the satellite from the ground.
16 Kathleen M. Mogan and Frank P. Mintz, *Keeping Track* (NASA Goddard Space Flight Center, 1992), p. 15.
17 Alfred Rosenthal, *Vital Links* (NASA Goddard Space Flight Center, 1983), p. 54.
18 "Carnarvon Tracking Station," Technical Secretariat Group, Weapons Research Establishment, Department of Supply, 1963, p. 6.
19 Kronmiller interview from *Keeping Track*.
20 See Note 18.
21 Rosenthal, p. 55.
22 William M. Hocking, "The Evolution of the STDN," *International Telemetering Conference,* 16, 80-01-03.
23 Nimmen, Bruno and Rosholt, pp. 57–59.
24 Edmond C. Buckley "Requirement for Establishment and Operation of 40-foot Parabolic Antenna at the Existing Minitrack Station in Santiago, Chile," Memorandum for the Office of International Programs, Folder Number 8799, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
25 See Note 5.
26 Chet Matthes was later the Station Director at Fort Myers, Florida. He passed away in 1988.
27 Clotaire Wood, "Morning Report to the Administrator," 2 January 1959, Folder Number 8807, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
28 "Fort Stewart History," *http://www.stewart.army.mil/ima/sites/about/history.asp* (accessed 5 September 2005).
29 Mogan and Mintz, p. 21.
30 The STADAN station at Fairbanks actually consisted of sites at nearby College and Gilmore Creek.

31 "Budget Estimates: FY 1969," IV, AO 2-34, National Aeronautics and Space Administration.
32 Gerald M. Truszynski, "Fatal Accident at NASA's Alaska Tracking Station," Memorandum to the Administrator, 7 May 1969, Folder Number 8805, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
33 Glen Nagle interview.
34 See Note 18, p. 1.
35 Robert A. Leslie to The Minister of Science, "An Annual Contribution by Australia to the Cost of the U.S. NASA Tracking Stations in Australia," 74/2967, 4 February 1976, Historical Records Box 18, NASA Canberra Office, Yarralumla, Australian Capital Territory.
36 "STADAN Facility, Orroral Valley, ACT: Information Brochure," The Department of Supply, Melbourne, Victoria, p. 1.
37 Ibid.
38 Ibid.
39 R. C. Davey to The Secretary of the Department of Science, "Australian Contribution to NASA Activities in Australia," 70/703, 17 October 1974, Historical Records Box 18, NASA Canberra Office, Yarralumla, Australian Capital Territory.
40 NASA News Release 63-240, 24 October 1963. Folder 8820, NASA Historical Reference Collection, NASA Headquarters, Washington, DC. Goddard's Applications Technology Satellite (ATS) project would become one of the most scientifically productive satellite programs ever devised by NASA. For example, using the Hawaii Station, the University of Hawaii utilized ATS-3 to communicate with South Pacific islands. Medical data and problems were relayed to the hospital at the university from these remote islands and in return, the university transmitted back the remedies.
41 Mogan and Mintz, pp. 18–19.
42 The $5 million tag broke down as follows: Site development and utilities $477K; Facility construction $1.1M; Tracking and data equipment $3.1M; Design and engineering services $337K. ("Satellite Tracking and Data Acquisition Facilities Fiscal Year 1962 Construction and Facilities Estimates, Rosman Data Acquisition Facility, Project No. 3379," 14 Feb 1962, Folder 8820, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.)
43 "Data Acquisition Facility, Rosman, NC," NASA Goddard Space Flight Center Brochure, Folder Number 8820, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
44 Ibid.
45 Ibid.

46 NASA News Release 63-279, Folder Number 8815, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
47 McKeehan interview from *Vital Links*.
48 Transportable equipment was also used in Brasilia, Brazil to obtain telemetry data on the Van Allen Radiation Belt on Explorer 15 in 1962. Much of this equipment was also sent to Majunga in early 1964.
49 Letter from the Director, Office of Tracking and Data Acquisition to the Office of International Programs, "Establishment of a Station in South Africa to Provide Supplementary Coverage to a Station Located in Zanzibar," 03 March 1964, Folder Number 8815, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
50 See Note 47.
51 In addition to an Assistant Station Director at some sites, another Civil Servant was occasionally assigned to a station, such as a Training Supervisor or a NASCOM Switching Center Supervisor. (Charles Force email 21 March 2006 and review notes 14 September 2006)
52 These were not the same aerospace primes that Goddard contracted to design, develop, and fabricate the satellites themselves. This list included aerospace giants such as Grumman Aircraft Engineering Corporation on the Orbiting Astronomical Observatories (OAO), Hughes Aircraft Company for the Applications Technology Satellites (ATS) and General Electric for the Nimbus spacecraft.
53 The other six companies ahead of Bendix were all prime contractors working directly on the Apollo spacecraft or its Saturn V launch vehicle: North American Rockwell, Grumman, Boeing, McDonnell, General Electric, and IBM.
54 Nimmen, Bruno and Rosholt, pp. 203–226.
55 Hunsicker interview from *Keeping Track*.
56 Blossom Point operated as part of STADAN until September 1966, when NASA ceased joint operations with the Navy. The site is still used today by the NRL as a primary Navy satellite control facility. ["Blossom Point," *http://www.globalsecurity.org/military/facility/blossom-point.htm* (accessed 02 September 2005)]
57 Mogan and Mintz, pp. 22–23, 42–43.
58 Stelter interview from *Vital Links*.
59 Rosenthal, pp. 181–182.
60 For example, Orroral Valley used the switching center located at Deakin, in the Canberra suburbs. In fact, NASA was Telstra's (Australian telephone company) biggest customer in the 1960s and 1970s. (Mike Dinn email, 16 March 2006)
61 See note 58.

62 Rosenthal, pp. 182–183.
63 Ibid., p. 59.
64 Ibid.
65 Ibid., pp. 185–186.
66 Ibid., pp. 187–188.

Chapter 3

1 This includes 302 paid employees stationed at Wallops.
2 *Orbiting Solar Observatory Satellite OSO-1* (National Aeronautics and Space Administration Special Publication-57, 1965).
3 Gagarin was promoted to the rank of Flight Major immediately upon his return.
4 Kenneth Gatland, "Manned Spacecraft," (Macmillan Publishing Company, Inc., New York, 1976), pp. 104–111.
5 From the minutes, Panel for Manned Space Flight, September 24, 30 and October 1, 1958, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
6 William R. Corliss, *History of the Goddard Networks* (NASA Goddard Space Flight Center, 1969), pp. 92–101.
7 Bill Wood interview from *Vital Links*.
8 Kathleen M. Mogan and Frank P. Mintz, *Keeping Track* (NASA Goddard Space Flight Center, 1992), p. 29.
9 Alfred Rosenthal, *Vital Links* (NASA Goddard Space Flight Center, 1983), pp. 69–70.
10 See Note 7.
11 Although planned, live television from the spacecraft never became a reality on Mercury. It had to wait until Apollo 7.
12 See Note 7.
13 Rosenthal, p. 75.
14 Mogan and Mintz, pp. 30–31.
15 "The Manned Space Flight Tracking Network (MSFTN)," description brochure, NASA Goddard Space Flight Center, 1965.
16 Rosenthal, p. 83.
17 Bill Wood email, 25 April 2006.
18 Bill Wood thinks the Super Constellation operated by NASA may in fact have been none other than President Eisenhower's old airplane, the *Columbine*.
19 John Saxon, who coordinated operations at the Honeysuckle Creek station, tells of how reports of UFO sightings would rise whenever testing with the Super Constellation, with all its blinking lights, was done.
20 Dave Harris email, 21 March 2006.
21 See Note 15.

22 Covington interview from *Vital Links*.
23 Henry Thompson and his wife tragically perished when Air New Zealand Flight 901 crashed into Mount Erebus in Antarctica on 28 November 1979 killing all 257 onboard. (Charles T. Force interview)
24 See Note 22.
25 Bill Wood email.
26 See Note 22.
27 Ibid. Former Goddard Center Director Harry Goett called Ozzie Covington "Mr. Manned Net" and some of his colleagues called him "Mr. Radar." They all credit him with a unique understanding of the technical and management requirements that made the network succeed.
28 Prior to the formation of the Office of Tracking and Data Acquisition, there was considerable debate at NASA about the most effective way to organize Headquarters management. Some preferred a functional management structure (propulsion, space research, etc.) while others wanted project type management with special offices for human spaceflight, scientific satellites, and so on. The final decision favored a project management structure.
29 Western Electric, Inc., "Final Project Report to NASA: Project Mercury," NAS1-430, pp. 42–45, June 1961.
30 Ibid.
31 See Note 7.
32 Lynn Dunseith interview from *Vital Links*.
33 The first two human Mercury flights (Alan B. Shepard and Virgil I. "Gus" Grissom) were suborbital, using the Army's Redstone rocket as launch vehicles. Because of their short range, Bermuda was not needed. It was not until beginning with the next flight when John Glenn was launched atop an Air Force Atlas ICBM for an attempt at orbital flight did the Bermuda Station come into play.
34 *The Royal Gazette*, 11 April 1961, p. 1, Folder Number 8808, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
35 Robert E. Spearing interview.
36 See Note 34.
37 See Note 29.
38 E. J. Kerrigan, Memorandum of Record, undated. Folder Number 8810, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
39 "The History of Bendix," *http://www.bfec.us/bfectxt6.htm* (accessed 18 June 2005).
40 Virg True email to Charles Force, 24 April 2006.
41 Ibid.
42 Ibid.
43 Ibid.

44 Ibid.
45 Russell Howe, *The Washington Post*, 03 December 1961, Folder Number 8819, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
46 Henry Tanner, "Nigeria Tracking Station Set Up in Desolate Area Near Aged City," *The New York Times*, 21 February 1962, Folder Number 8819, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
47 Hugh L. Dryden to Keith Glennan, "Mercury Tracking Station in Mexico," 17 September 1959, Folder Number 8817, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
48 Ibid.
49 Edmond C. Buckley to Director, Office of Space Flight Programs, "Review of Some of the Inter-governmental Agreements for the Mexican Station," 23 April 1961, Folder Number 8817, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
50 Ibid.
51 Ibid.
52 Ibid.
53 Ray W. Hooker, Assistant Chief, Engineering Service Division, "Tracking and Ground Instrumentation Systems for Project Mercury, Special Report on African Sites," Memorandum for File, 20 October 1959, Folder Number 8819, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
54 Ibid.
55 Ibid.
56 Henry Clements interview from *Vital Links*.
57 Swenson, Grimwood, Alexander, *This New Ocean: A History of Project Mercury* (National Aeronautics and Space Administration Special Publication-4201, 1998), pp. 213–220, 647–648.
58 N. Pozinsky to Ruech, Naval Facilities Engineering Command, "Grand Canary Island: Replacement Housing for Permanent and Migrant Farm Workers," Folder Number 8809, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
59 Ibid.
60 Corliss, pp. 150–155.
61 Mogan and Mintz, pp. 35–36.
62 Ibid.
63 It is well known within NASA circles that Donald K. "Deke" Slayton, who for many years ran Flight Crew Operations in Houston, would assign members of the Astronaut Office to "nice locations" such as Australia or Hawaii as reward (rest & recreation) for his people.

64 "Carnarvon Tracking Station," Technical Secretariat Group, Weapons Research Establishment, Department of Supply, 1963, p. 7.
65 See Note 15.
66 Rosenthal, pp. 89–91.
67 Mogan and Mintz, p. 35.
68 Rosenthal, pp. 83–84.

Chapter 4

1 William R. Corliss, History of the Goddard Networks (NASA Goddard Space Flight Center, 1969), pp. 156–157.
2 David West Reynolds, "Apollo: The Epic Journey to the Moon" (Tehabi Books, Inc., 2002), p. 41.
3 Memorandum for the Vice President, John F. Kennedy, 20 April 1961 and Robert C. Seamans, Jr., *Project Apollo: The Tough Decisions* (National Aeronautics and Space Administration Special Publication-2005-4537, 2005), p. 13.
4 Robert C. Seamans, Jr., *Project Apollo: The Tough Decisions* (Monographs in Aerospace History No. 37, SP-2005-4537), pp. 11–21.
5 Alfred Rosenthal, *Vital Links* (NASA Goddard Space Flight Center, 1983), pp. 111–113.
6 Barton C. Hacker and James M. Grimwood, *On the Shoulders of Titans* (National Aeronautics and Space Administration Special Publication-4203, 1977).
7 See Note 1.
8 James R. Hansen, "First Man: The Life of Neil Armstrong," p. 236, Simon and Shuster, 2005.
9 Lyn Dunseith interview from *Vital Links*.
10 George Gray, "The UNIVAC 418 Computer," *Unisys History Newsletter*, 4:2, August 2000.
11 Hacker and Grimwood, p. 592.
12 "Carnarvon Tracking Station," Technical Secretariat Group, Weapons Research Establishment, Department of Supply, 1963, p. 4.
13 Rosenthal, pp. 114–116.
14 "The Manned Space Flight Tracking Network (MSFTN)," description brochure, NASA Goddard Space Flight Center, 1965.
15 Bill Schneider interview from *Vital Links*.
16 In November 1963, Secretary of Defense Robert S. McNamara reorganized the DOD national ranges, transferring much of the Pacific Missile Range from the Navy to the Air Force. McNamara also entrusted the latter with the overall management of all DOD ground tracking facilities. Following those actions, the Air Force renamed the Atlantic Missile

Range and the Pacific Missile Range to Eastern Test Range (ETR) and Western Test Range (WTR), respectively.

17 Hacker and Grimwood, pp. 590–592.

18 R. Owen, "Evolution of Telemetry, Command and Voice on the MSFN," memorandum to OWU, Goddard Space Flight Center, 29 January 1991.

19 Pan American World Airways, Inc., Aerospace Services Division, Public Relations MU517, Folder Number 8807, NASA Historical Reference Collection, NASA History Division , NASA Headquarters, Washington, DC.

20 Robert C. Seamans, Jr., Harold Brown, "Memorandum of Agreement on Operation and Support of NASA Instrumentation Facilities on Antigua and Ascension," 22 May 1965, Folder Number 8807, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

21 Ibid.

22 Proceedings of the Apollo Unified S-Band Technical Conference, NASA-SP-87, 1965.

23 "Tracking and Data Acquisition Facility Ascension Island," 25 June 1965, Folder Number 8807, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

24 Benson interview.

25 See Note 22.

26 Gerald M. Truszynski, "Construction of Apollo Unified S-Band Facilities on Antigua B.W.I. and Grand Bahama Island," 16 June 1965, Folder Number 8806, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

27 Norman Pozinsky, "Memorandum of Communication: Agreement to Establish the Apollo Station on Antigua, BWI," 20 July 1966, Folder Number 8806, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

28 H. R. Brockett to Carl Jones "Antigua Apollo Station," 28 July 1966, Folder Number 8806, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

29 Ref: Edmond C. Buckley to Dr. Harry J. Goett, Technical Note, 22 July 1964, Folder Number 8810, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

30 "Interagency Meeting to Discuss U.S. Requirements for Canton Island," Office of Tracking and Data Acquisition, Memorandum for File, 05 August 1964, Folder Number 8810, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

31 Bendix was also the contractor for the Federal Aviation Administration. The FAA was still providing onsite support on Canton Island to the Department of Defense even though its own requirement there had ceased nearly a year ago.

32 E. C. Buckley, " Ascension Island Power Plant," Technical Note Director of the Office of Tracking and Data Acquisition to AFETR, Patrick Air Force Base, 18 June 1965, Folder Number 8807, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
33 James C. Bavely, "Ascension Island Operations," Technical Note to H. R. Brockett, 26 April 1967, Folder Number 8807, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
34 Letter from NASA Headquarters to Dr. H. J. Goett, "Zanzibar Station," 23 May 1963, Folder Number 8824, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
35 Letter from L. F. Griffin to Edmond C. Buckley, Bendix Field Engineering Corporation, 11 March 1964, Folder Number 8824, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
36 Administrator's Briefing Memorandum, 22 January 1964, Folder Number 8824, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
37 Letter from NASA Administrator to the Secretary of State, 19 March 1964, Folder Number 8824, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
38 N. R. Brockett, "Status of Zanzibar," Memorandum for Mr. Buckley, 13 April 1964, Folder Number 8824, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
39 Howard Simons, "LBJ Orders Space Station Out of Zanzibar," The Washington Post, 08 April 1964, Folder Number 8824, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
40 NASA News Release 63-279, Folder Number 8815, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
41 Letter from the Director, Office of Tracking and Data Acquisition to the Office of International Programs, "Establishment of a Station in South Africa to Provide Supplementary Coverage to a Station Located in Zanzibar," 03 March 1964, Folder Number 8815, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
42 James C. Bavely, "Staffing at Malagasy for Satellite and Gemini Programs," 13 October 1964, Folder Number 8815, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

43 Former Deputy Associate Administrator David Harris recalls that land on Guam became an issue later on when the landlord decided to significantly increase the leasing cost.
44 Edmund C. Buckley to Dr. Hugh L. Dryden, "Visit of Governor Manuel F. L. Guerrero Territory of Guam," 10 June 1964, Folder Number 8813, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
45 Force interview.
46 The section of the Operations Building labeled Diner was a cafeteria added after the station was operational. The only eating facility initially provided was a small kitchen, sized and equipped as one in an average home—and totally inadequate for the station staff. There were no restaurants within reasonable driving distance. During operations, personnel had to remain on-site anyway. Station Director Force requested vending machines to remedy this deficiency. But Goddard denied his request, explaining that since the station had no on-site cafeteria (as most stations had), it clearly lacked the expertise to stock food vending machines! (Charles T. Force email 14 September 2006.)
47 See Note 45.
48 See Note 45.
49 "New Bermuda Radar Selected for Apollo Moon Mission Support," GSFC News Release No. G-9-65, 08 April 1965, Folder Number 8808, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
50 Director, Office of Tracking and Data Acquisition, "Unified S-Band Facility Bermuda; Project 9831 Revised," Administrator's Briefing Memorandum, 10 March 1965, Folder Number 8808, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
51 Lorne M. Robinson to T. V. Lucas, "Chronology of Requirements for Unified S-band Systems at Grand Bahama Island (GBI) and Grand Turk Island (GTI)," 09 February 1966, Folder Number 8811, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
52 Ibid.
53 "Mexico, U.S. Extend Agreement for Operation of Guaymas Tracking Station," NASA News Release 65-76, 4 March 1965, Folder Number 8817, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
54 N. Pozinsky, Chief, Facilities and Station Implementation to Director, Office of Tracking and Data Acquisition, "Guaymas Station Land Requirements for Apollo USB," 10 May 1965, Folder Number 8817,

NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

55 Edmond C. Buckley to Morton Berndt, "Guaymas Station Importance," 6 August 1965, Folder Number 8817, NASA Historical Reference Collection, NASA Headquarters, Washington, DC.

56 Former Associate Administrator for Tracking and Data Systems, Bill Schneider, would call Gemini 8 as the network's finest moment during the Gemini program. He explained why. "During Gemini 8 as astronauts Armstrong and Scott docked with their Agena target vehicle, just as they left the line of sight of the Madrid Madagascar tracking station and before they were acquired by Australia, a technical problem with the Agena caused them to spin wildly. So, after they were reacquired, the decision was made to end the flight prematurely and arrange for recovery at an alternate location in the Pacific. This was the first and the only time that NASA had to use a contingency landing site. With the help of the very excellent tracking network, we landed the spacecraft safely near a U.S. destroyer in the middle of the Pacific Ocean. It was a real test of our ability to communicate and to locate a spacecraft in a far away, strange and unexpected environment." (Schneider interview from *Keeping Track*.)

57 Kenneth Gatland, *Manned Spacecraft* (Macmillan Publishing Company, Inc., New York, 1976), pp. 185, 275–276.

Chapter 5

1 Kathleen M. Mogan and Frank P. Mintz, *Keeping Track* (NASA Goddard Space Flight Center, 1992), p. 44.

2 Ibid.

3 Alfred Rosenthal, *Vital Links* (NASA Goddard Space Flight Center, 1983), p. 136. Three locations spaced approximately 120° apart in longitude were required to provide seamless coverage of a lunar spacecraft over 24 hours.

4 Mogan and Mintz, pp. 48-49.

5 R. Owen, "Evolution of Telemetry, Command and Voice on the MSFN," memorandum to OWU, Goddard Space Flight Center, 29 January 1991.

6 Ibid.

7 Linda Neuman Ezell, *NASA Historical Data Book, Volume III: Programs and Projects 1969-1978* (National Aeronautics and Space Administration Special Publication-4012, 1994), Table 6-32.

8 "The Worldwide Deep Space Network" (NASA Jet Propulsion Laboratory JPL 400-326, May 1989).

9 William R. Corliss, *History of the Goddard Networks* (NASA Goddard Space Flight Center, 1969), p. 131.

10 Mogan and Mintz, pp. 49–51.
11 Gerald M. Truszynski to Donald Crabill, "The Need for Apollo Ships," 05 March 1964 Folder Number 8792, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
12 In the letter, Truszynski referred to these stations as Pretoria and Mauritus (Mauritius), respectively.
13 See Note 11.
14 Ibid.
15 Ibid.
16 There was originally concern by NASA regarding the reliability of communications with the tracking ships. Because of this, NASA installed flight control consoles in them—a move that was distinctively counter to the MSFN trend toward centralizing all control functions at the Mission Control Center in Houston. Though installed, these control consoles were never actually used on a real mission.
17 A particular concern of Apollo engineers was reentry tracking, that is, locating the position of the Command Module during the communication blackout while the spacecraft was surrounded by a layer of super-heated plasma during reentry. Because the transponders were also blacked out during this period, the C-band radars lost this tracking aid. Reentry tracking of the CM returning from the Moon was more difficult than for vehicles returning just from Earth orbit since reentry could occur over a larger corridor at a much higher velocity. In addition, the Command Module had a center-of-gravity offset allowing the capsule to fly a lifting trajectory using roll maneuvers. In this manner, the trajectory could be controlled. For energy management, the capsule first plunged into the atmosphere and then briefly skipped out of the atmosphere before making its final descent towards the recovery area. During the early 1960s, the acquisition problem was considered potentially serious. A radio interferometer was even proposed by Mengel's group as a solution. In the end, a skin-tracking radar was designed and installed on the recovery ship *Huntsville*.
18 Apollo Instrumentation Ships Technical and Management Problems, 12 June 1967, Folder 8792, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
19 Ibid.
20 Ibid.
21 Letter from T. O. Paine to Senator Clinton P. Anderson, 28 October 1969, NASA Office of the Administrator, Folder Number 8792, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
22 Ibid.
23 Ibid.
24 Ibid.

25 Ibid.
26 Edmond C. Buckley to Harry J. Goett, Requirements for Instrumentation Aircraft for Support of Apollo, 8 January 1966, Folder Number 8798, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
27 Ibid.
28 Letter from H. R. Brockett to Robert C. Seamans, Jr., 29 May 1967, ARIA Aircraft, Folder Number 8798, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
29 "Fact Sheet: Advanced Range Instrumentation Aircraft," Office of Information, United States Air Force Systems Command, November 1976.
30 W. L. Folsom, Action Item (OTDA) Clarification of NASA Requirements for ARIA, 02 May 1966, Folder Number 8798, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
31 As part of an Air Force consolidation of large test and evaluation aircraft, basing for the ARIA was transferred from the Eastern Test Range at Patrick Air Force Base in Florida to the 4950th Test Wing at Wright Patterson Air Force Base near Dayton, Ohio in December 1975. In 1994, the ARIA fleet was relocated to Edwards Air Force Base, California, as part of the 452nd Flight Test Squadron in the 412th Test Wing. The final flight of ARIA took place on 24 August 2001.
32 Edmond C. Buckley was the NASA Vice Chairman of the panel. Christopher C. Kraft represented the Manned Spacecraft Center and Ozro M. Covington the Goddard Space Flight Center. The Air Force Eastern Test Range at the time had a critical need for the ARIA in order to support testing activities for development of the Navy's Poseidon submarine launched ballistic missile.
33 Edmond C. Buckley, NASA/DOD ARIA Management Agreement, 26 January 1965, Folder Number 8798, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
34 George E. Mueller to Buckley, Instrumentation Aircraft Support, 11 May 1964, Folder Number 8798, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
35 Letter from H. R. Brockett to Robert C. Seamans, Jr., 29 May 1967, A/Ria Aircraft, Folder Number 8798, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
36 See Note 7.
37 "ARIA 328 Memorial," *http://www.flyaria.com/memorial/1999/personal.htm* (accessed 27 December 2005).
38 "Intelsat," Jet Propulsion Laboratory Mission and Spacecraft Library, *http://msl.jpl.nasa.gov/Programs/intelsat.html* (accessed 12 October 2005).

39 At the speed of light, it takes approximately 1.3 seconds for radio signals to travel from Earth to the Moon.
40 They were: Antigua, Ascension, Bermuda, Canary Island, Canberra, Cape Canaveral, Carnarvon, Corpus Christi, Goldstone, Guam, Guaymas, Hawaii, Grand Bahama, Madrid.
41 Corliss, pp. 244–249.
42 Ibid.
43 Force email.
44 Letter from James Webb to E. S. Terlaje, 7 April 1967, Folder Number 8813, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
45 Brooks, Grimwood, Swenson, *Chariots for Apollo* (National Aeronautics and Space Administration Special Publication-4205, 1979), Chapter 9.
46 Phillips to Administrator, "Apollo 5 Mission (SA-204/LM-1) Post Launch Report #1," 12 February 1968.
47 See Note 45.
48 Ibid.
49 Ibid.
50 The first use of television on a human flight by NASA was actually on Mercury Atlas 9, where a camera was trained on astronaut L. Gordon Cooper mainly to monitor his movements and behavior during the 34-hour mission. Three Mercury ground stations were set up to receive the slow-scan television pictures. However, they could not be broadcast live to an audience.
51 Henry P. Yschek, MSC, to North American, Contract Change Authorization 95, 24 Sept. 1963; William A. Lee to Mgr., ASPO, "The case for television transmission during LEM descent and ascent," 27 April 1964.
52 Phillips to Manager, ASPO, "Apollo On-board TV," 10 April 1968.
53 Walter Cunningham, *The All-American Boys* (Simon & Shuster, Inc., 2004), p. 155.
54 "The Fresnedillas (Madrid, Spain) MSFN Station," *http://www.honeysucklecreek.net/other_stations/fresnedillas/intro.html* (accessed 02 November 2005).
55 Apollo 8 Mission Commentary, 24 December 1968, tapes 242-3, 277-1.
56 Robert Zimmerman, *Genesis: The Story of Apollo 8* (Random House, Inc., 1998), pp. 210–211, 240–249.
57 "American Experience: Race to the Moon," *http://www.pbs.org/wgbh/amex/moon/peopleevents/e_telecasts.html* (accessed 07 November 2005).
58 Brooks, Grimwood, Swenson, Chapter 12.
59 "Apollo 15 Camera Equipment," *http://www.lpi.usra.edu/expmoon/Apollo15/A15_Photography_cameras.html#COLORTV* (accessed 07 November 2005).
60 Bill Wood email.

61 Kerrie Dougherty, John Sarkissian, "Dishing Up the Data: The Role of Australian Space Tracking and Radio Astronomy Facilities in the Exploration of the Solar System," IAC-02-IAA.2.3.01, 2002. Also see John Sarkissian, "On Eagles Wings: The Parkes Observatory Support of Apollo 11 Mission," Astronomical Society of Australia, Volume 18, 2001.
62 Ibid.
63 Ibid.
64 Ibid.
65 Glen Nagle interview.
66 See Note 61 and Nagle interview.
67 See Note 65.
68 See Note 61.
69 Ozzie Covington interview from *Vital Links*.
70 Bill Wood interview from *Vital Links*.
71 Dinn interview.
72 Ibid.
73 Robert Owen interview from *Vital Links*.
74 "Apollo and the Dish Down Under," CSIRO Media Release 2000/266, 12 October 2000.
75 See Note 61.
76 Tom Reid was the colorful Station Director at Honeysuckle Creek during the Apollo missions. He had a long and distinguished association with NASA and was one of the longest serving Station Directors. He first became involved with NASA while working with the Weapons Research Establishment at Woomera in the 1958-1962 time period. He became the first Station Director at Orroral Valley in 1964, and in 1967 was appointed Director at Honeysuckle Creek, where he provided inspiration and leadership during the lunar landings. In 1970, he began an 18-year assignment as Director of the Tidbinbilla Deep Space Communications Complex. Reid was awarded the Member of the Order of the British Empire (MBE) in January 1970 in recognition of his contribution to Australia meeting its commitments to the Manned Space program. It was actually bestowed upon him by Her Majesty the Queen when she was in Australia during the Apollo 13 mission. She happened to ask him how the mission was going when she presented it. (Charles T. Force review comments, 14 September 2006.)
77 Lyn Dunseith interview from *Vital Links*.
78 Chris Kraft interview from *Vital Links*.
79 "Experiment Operations During Apollo EVAs," ARES Publications, *http://ares.jsc.nasa.gov/HumanExplore/Exploration/EXLibrary/docs/ApolloCat/Part1/ALSEP.htm* (accessed 8 November 2005).
80 Although the Lunar Roving Vehicle had a total range capability of 91 kilometers (57 miles), the astronauts would not have the time nor safety margin

to fully use this capacity. On Apollo 15, the LRV was driven a total of 27.7 kilometers (17.2 miles) with a maximum range from the Lunar Module being 5 kilometers (3.1 miles). On Apollo 16, the total was 26.7 kilometers (16.6 miles) and reached a distance of 4.5 kilometers (2.8 miles) from the LM. The Apollo 17 LRV accumulated 35.9 kilometers (22.3 miles) with a maximum distance of 7.5 kilometers (4.7 miles) from the LM.

81 Mogan and Mintz, p. 55.

82 Robert Barnes interview from *Vital Links*.

83 See Note 77.

84 Helen T. Wells, Susan H. Whiteley, Carrie Keregeannes, *Origins of NASA Names* (National Aeronautics and Space Administration Special Publication-4402, 1976), p. 109. The name 'Skylab,' a contraction connoting 'laboratory in the sky,' was suggested in 1968 by Lt. Colonel Donald L. Steelman of the United States Air Force while assigned to NASA. He later received a token award for his suggestion.

85 W. David Compton, Charles D. Benson, *Living and Working in Space: A History of Skylab* (National Aeronautics and Space Administration Special Publication-4208, 1983), Chapter 14.

86 Mogan and Mintz, p. 61.

87 Russell P. Patera, William H. Ailor, "The Realities of Reentry Disposal," The Aerospace Corporation, p. 6, 2001.

88 Carolynne White, GSFC News Release 89-2, 13 January 1989, Folder Number 8818, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

89 Ibid.

90 "Chronology: Beginnings of ASTP," NASA History Division, *http://history.nasa.gov/astp/chrono.html* (accessed 09 November 2005).

91 Edward Clinton Ezell and Linda Newell Ezell, *The Partnership* (National Aeronautics and Space Administration Special Publication-4209, 1978).

92 Mogan and Mintz, pp. 63–64.

93 Bill Wood email.

94 Donald H. Martin, "Communication Satellites, Fourth Edition," (The Aerospace Corporation Press, 2000), Chapter 1.

95 On Apollo-Soyuz, a transportable station with a 40-foot automatic tracking antenna was set up near Madrid to supplement the 100-foot antenna located at Buitrago, serving as the primary ground relay point between the ATS-6 satellite and the rest of the network.

96 See Note 94.

97 "U.S. Tracking Soyuz 16," JSC News Release No. 74-272, 03 December 1974, Folder Number 8781, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

98 Watson interview.

99 Rosenthal, pp. 189–190.
100 Ibid.
101 Kenneth Gatland, *Manned Spacecraft* (Macmillan Publishing Co., Inc., New York, 1976), pp. 249–252.
102 In what could have turned the first international space mission from an unparalleled success into tragedy, a series of events during reentry led to the three American astronauts accidentally inhaling noxious fumes from the Command Module's Reaction Control System. This led to an unanticipated two week hospital stay for the crew in Honolulu. For Deke Slayton, it also meant the discovery of a small lesion on his left lung. An exploratory operation indicated it was a nonmalignant tumor. After a short convalescence, Slayton joined the four other ASTP crew members for two celebratory tours, one in the Soviet Union and the other in the United States.
103 See Note 78.
104 Report by the Subcommittee on Aeronautics and Space Technology of the Committee on Space Sciences and Astronautics, United States House of Representatives Ninety-Third Congress Second Session, September 1974.
105 Mogan and Mintz, pp. 56.

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1 Jane Van Nimmen, Leonard C. Bruno and Robert L. Rosholt, *NASA Historical Data Book Volume I: NASA Resources 1958–1968* (National Aeronautics and Space Administration Special Publication-4012, 1988), pp. 129.
2 Ihor Gawdiak with Helen Fedor, *NASA Historical Data Book, Volume IV: NASA Resources 1969–1978* (National Aeronautics and Space Administration Special Publication-4012, 1994). Contrary to the popular notion that NASA's budget peaked in 1969 and started to decrease only after the first lunar landing was achieved in July of that year, the Agency's funding actually peaked four years earlier when the FY 1965 NASA appropriation was $5,249,700,000. This had dropped to $3,994,993,000 by FY 1969. FY 1974 funding was $3,039,700,000 after which the NASA budget again began to increase so that by FY 1978, it reached $4,063,701,000.
3 Watson interview.
4 Ibid.
5 Gawdiak and Fedor, p. 68 and Judy A. Rumerman, *NASA Historical Data Book Volume VI 1979–1988* (National Aeronautics and Space Administration Special Publication-4012, 2000), p. 468.
6 Tracking and Data Acquisition Program, Subcommittee Report on Aeronautics and Space Technology, Ninety-Third Congress, Second Session, September 1974, Folder Number 8781, NASA Historical

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8 Kathleen M. Mogan and Frank P. Mintz, *Keeping Track* (NASA Goddard Space Flight Center, 1992), p. 68.

9 Ibid., pp. 56–58.

10 *Washington Evening Star*, Tuesday, 23 June 1970.

11 "Antigua Tracking Station Closing," 22 June 1970, NASA Press Release Number 70-101, Folder Number 8806, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

12 Gerald M. Truszynski to Assistant Administrator for International Affairs, "Closing of Antigua Tracking Station," 20 February 1970, Folder Number 8806, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

13 Gerald M. Truszynski to George M. Low, "Summary Status of Activities at Guaymas Station," Memorandum for File, 30 September 1970, Folder Number 8817, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

14 "Guaymas Tracking Station," NASA News Release 70-198, 13 November 1970, Folder Number 8817, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

15 Charles A. Taylor to Carl Mautner," Extension of Intergovernmental Agreement with Spain for the Operation of the Canary Island Station," 6 July 1973, Folder Number 8809, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

16 Gerald M. Truszynski to Colonel Daniel Oliver Osana, Technical Note, 22 January 1975, Folder Number 8809, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

17 T. O. Paine, Letter to the Honorable Robert P. Mayo, Director, Bureau of the Budget, 20 February 1970, Folder Number 8813, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

18 Ibid.

19 Ibid.

20 Douglas J. Mudgway, *Big Dish* (University Press of Florida, 2005), pp. 29–31.

21 South Africa first became involved in space research in 1957 during the International Geophysical Year. When the United States announced its intention to launch an artificial Earth satellite, South Africa, who was actively pursuing radio research, readily agreed to cooperate with the Smithsonian Astrophysical Observatory to establish and operate an optical tracking station (this at a time when no one was as yet fully convinced that artificial satellites could even get off the ground, not to mention be

seen or photographed from the ground once it was in orbit.) Thus when the State Department officially approached South Africa to operate a Minitrack station on behalf of the Naval Research Laboratory, it was received with great enthusiasm. South Africa knew that such a station on its soil would be the first to observe a satellite launched from Cape Canaveral after it had crossed the Atlantic.

22 *South African Panorama*, April 1986: 30-31, Folder Number 8849, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

23 R. D. Trishman, "South African Situation," Memorandum for Assistant Director, Space Flight Operations, 04 April 1960, Folder Number 8849, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

24 Edmond C. Buckley to the Office of International Programs, "Republic of South Africa," 9 November 1962, Folder Number 8849, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

25 *New York Times*, 28 June 1965, Folder Number 8849, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

26 Ibid.

27 *South African Sunday Times*, 22 April 1962, p. 1, Folder Number 8849, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

28 *Defense/Space Daily*, 22 March 1974.

29 "South Africa: NASA Inches Out of a Segregated Tracking Station," *Science*, 27 July 1973: 331-332, 380, Folder Number 8849, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC

30 "NASA to Phase Out African Stations," *Defense Space Daily*, 11 July 1973: 47, Folder Number 8849, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

31 See Note 29.

32 Letter from James C. Fletcher to Dr. C. v.d.m. Brink, President of the Council for Scientific and Industrial Research, 21 October 1975, Folder Number 8849, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

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34 Letter from R. H. Curtin, Director of Facilities to GSFC Director of Administration and Management, 12 December 1975, Folder Number 8849, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
35 See Note 28.
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37 Ibid.
38 "Pay Up or Lose Station Madagascar Tells NASA," *Washington Star*, 12 July 1975, Folder Number 8815, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
39 NASA Daily Activities Report, 8 April 1980, Folder Number 8815, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
40 George Low to James C. Fletcher, Memorandum for Record, 23 July 1973, Folder Number 8815, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
41 Mogan and Mintz, pp. 56–57, 68.
42 Force interview.
43 Ibid.
44 Jane Van Nimmen, Leonard C. Bruno and Robert L. Rosholt, *NASA Historical Data Book Volume I: NASA Resources 1958–1968* (National Aeronautics and Space Administration Special Publication-4012, 1988), pp. 57–59.
45 Force interview.
46 Ibid.
47 Linda Newman Ezell, *NASA Historical Data Book, Volume III: Programs and Projects, 1969-1978* (National Aeronautics and Space Administration Special Publication-4012, 1988) pp. 405–406.
48 Mogan and Mintz, pp. 56–57, 68.
49 "NASA Selects Tracking Contractor," NASA News Release 75-315, 17 December 1975, Folder Number 8781, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
50 The second satellite, LAGEOS 2, was deployed from Shuttle flight STS-52 on 22 October 1992. It was a joint program between NASA and the Italian space agency ASI, which built the satellite using LAGEOS 1 drawings and specifications as provided by NASA. LAGEOS 2's orbit was selected to provide more coverage of seismically active areas, such as the Mediterranean Basin and California, designed to help scientists understand irregularities noted in the motion of LAGEOS 1. Tracking stations were located in many countries, including the U.S., Mexico, France, Germany,

Poland, Australia, Egypt, China, Peru, Italy, and Japan. Data from these stations were made available worldwide to investigators studying crustal dynamics. LAGEOS 1 also contained a special message plaque addressed to humans in the far distant future, showing maps of the surface of Earth from three different eras: postulated appearance from 268 million years ago, present day and what the appearance might be at 8 million years in the future—the satellite's estimated decay date. (See Note 51.)

51 "LAGEOS 1, 2 Quicklook," Jet Propulsion Laboratory Mission and Spacecraft Library, *http://msl.jpl.nasa.gov/QuickLooks/lageosQL.html* (accessed 03 January 2006).

52 Mogan and Mintz, pp. 59.

53 Rosenthal, p. 198. Goddard Space Flight Center had 1,400 people working the network. The tracking stations had 1,110 people of whom some 500 were foreign nationals.

54 Rosenthal, p. 196.

55 Wes Bodin interview from *Keeping Track*.

56 Harry McKeehan interview from *Vital Links*.

57 The popular American TV program *60 Minutes* aired a program about 1989 called "Isle of Spies" about the Seychelles, in which CBS alleged NASA had a station in the Seychelles. The Seychelles *was* an important location since it was in the right place to view orbit adjustment maneuvers for polar launches from Vandenberg Air Force Base. Office of Space Communications Associate Administrator Bob Aller, through NASA's Public Affairs Office, subsequently advised *60 Minutes* that although NASA used the Air Force station on the Seychelles as appropriate, NASA did not and had never actually had a station there. The Agency never felt apologetic about using Air Force resources. In planning to rerun the story the following summer, *60 Minutes* contacted the new Associate Administrator Charles Force to verify Aller's information. For whatever reason, when the rerun aired, *60 Minutes* seemed to go out of their way in the lead-in to again call it a NASA station! NASA never felt defensive, nor did anyone seem to care. (Charles Force email, 24 September 2005.)

58 Judy A. Rumerman, *NASA Historical Data Book Volume VI 1979-1988* (National Aeronautics and Space Administration Special Publication-4012, 2000), pp. 342–349.

59 *www.wstf.nasa.gov/WSSH/* (accessed 05 January 2006). In addition to the dry lakebeds of Edwards Air Force Base and the 15,000-foot runway at the Kennedy Space Center, a secondary backup landing site is located at the White Sands Space Harbor in southern New Mexico. Two 35,000-foot hard-packed, gypsum landing strips provide what the Space Shuttle needs in an emergency: long, forgiving runways. The Tula Peak Station served the communication needs in the event of a White Sands landing. TULA was closed-out following STS-2 but reopened briefly to

provide just such a capability when STS-3 landed at White Sands on 30 March 1982 (the only Shuttle landing there to date).

60 Mogan and Mintz, p. 68.

61 Joseph P. Allen, Assistant Administrator for Legislative Affairs to The Honorable Roy A. Taylor, 24 May 1976, Folder Number 8820, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

62 NASA Daily Activities Report, 23 February 1981, Folder 8820, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

63 Rumerman, pp. 342–349.

64 James M. Beggs, Letter to the Subcommittee on Space Science and Applications, Committee on Science and Technology, 04 January 1985, Folder Number 8805, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

65 Ibid.

66 "Quito Tracking Station Shuts Down," Goddard News, 15 December 1981: 4, Folder Number 8801, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

67 "Quito NASA Satellite Tracking And Data Acquisition Facility: A Story of Excellence," Ecuadorian Services Company, 2006.

68 Benson interview and Force email (24 September 2006).

69 See Note 67.

70 See Note 66.

71 R. E. Smylie to the Administrator, "Closure of the Quito STDN Station," 1 September 1981, Folder Number 8801, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

72 The landing of STS-3 on 30 March 1982 is, to date, the only Shuttle landing ever at the White Sands Space Harbor.

73 Rumerman, pp. 342-349. [Pioneer (DSS 11), the original Goldstone station, was deactivated in 1981 and has been designated a National Historic Landmark by the United States Department of the Interior.]

74 "The Fresnedillas MSFN Station," *www.honeysucklecreek.net/other_stations/fresnedillas/main.html* (accessed 10 January 2006) and "Madrid Space Station," NASA Publication P72-223JPL, 31 August 1972.

75 Kerrie Dougherty email to Glen J. Nagle, 7 March 2006.

76 Saxon interview.

77 Hamish Lindsay, "Tracking Apollo to the Moon" (Springer, 2001).

78 Letter from Joseph F. Ada to James Fletcher, 21 December 1988, Folder Number 8813, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

79 Henry Iuliano, "NASA Phases Down Guam Tracking Station," Goddard News, September 1989, Folder Number 8813, NASA Historical Reference

Collection, NASA History Division, NASA Headquarters, Washington, DC.

80 See Note 55.

81 Carolynne White, GSFC News Release 89-2, 13 January 1989, Folder Number 8818, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

82 Ascension and Guam were both quite remote. A large power converter once failed at a station and analysis revealed a mechanical design flaw. A modification was quickly designed and teams were dispatched to all stations around the world to install the modification—to all stations, that is, except Ascension and Guam. These two stations received in the mail a small bag of parts with some instructions! (Charles Force email, 24 September 2006)

83 John F. Murphy, Letter to Senator Pete V. Domenici, 07 July 1982, Folder Number 8807, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

84 Jeffrey M. Lenorovitz, "ESA Seeks U.S. Tracking Agreement, New Downrange Station for Ariane," Aviation Week & Space Technology, 7 January 1985: 117.

85 Ibid.

86 Thomas L. Matlick, "Ascension Closure," TN-88-310, 29 December 1988, Folder Number 8807, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

87 David Harris email.

88 Thomas L. Matlick, "Closure of the Ascension Island Tracking Station," TN-89-023, 30 January 1989, Folder Number 8807, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

89 Thomas L. Matlick, "Ascension Island Tracking Station," TN-89-055, 21 February 1989, Folder Number 8807, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

90 See Note 68.

91 "Questions and Answers on the STDN," NASA News Release Number 89-6, 1 February 1989, Folder Number 8781, NASA Historical Reference Collection, NASA Headquarters, Washington, DC. (The personnel breakdown of contractors by location in 1989 were as follows: Ascension 43, Bermuda 77, Dakar 16, Guam 102, GSFC 227, Hawaii 67, MILA/PDL 129, Santiago 75, Wallops 4, White Sands 375; for a total of 1,115.)

92 Judy A. Rumerman, *NASA Historical Data Book Volume VI 1979-1988* (National Aeronautics and Space Administration Special Publication-4012, 2000), pp. 342–349.

Chapter 7

1 Arthur C. Clarke, "Extra Terrestrial Relays: Can Rocket Stations Give Worldwide Radio Coverage?" *Wireless World*, October 1945: 305–308.

2 David J. Whalen, "Communications Satellites: Making the Global Village Possible," unpublished article. The geosynchronous or geostationary orbit is known in some circles as the Clarke Orbit in honor of Arthur C. Clarke. However, it is not exactly clear that his article was actually the inspiration for modern telecommunications satellites. Pierce has stated that the idea was "in the air" at the time and certain to be developed regardless of Clarke's publication.

3 Ibid.

4 Glen E. Cameron, "Ground Station Design and Operation," pp. 7–13, 14, Applied Technology Institute, Clarksville, Maryland, 1998.

5 The first major three-axis stabilized geosynchronous satellite project was the DOD's classified Advent communications satellite. It was large and heavy. At over 500 pounds, at the time it could only be launched by the Air Force's Atlas-Centaur launch vehicle. The Advent never flew, primarily because the Centaur upper stage was not fully reliable until 1968. When the program was canceled, it was seen by many as the death knell for the three-axis, stable-platform, geosynchronous satellite. This was a premature prognosis, as many characteristics of the Advent would end up becoming commonplace in satellites less than 10 years later.

6 See Note 2.

7 There has often been confusion with respect to the acronym "TDRS," which refers to the Tracking and Data Relay Satellite itself, versus "TDRSS," which refers to the Tracking and Data Relay Satellite System, including the ground terminals. Both are pronounced the same ("tid-dres").

8 Ken Atchison, "NASA to Change Tracking and Data Acquisition Operations," News Release Number 89-172, 7 December 1989, NASA Headquarters.

9 Kathleen M. Mogan and Frank P. Mintz, *Keeping Track* (NASA Goddard Space Flight Center, 1992), p. 74.

10 A ground terminal situated outside of United States territory could have offset the coverage loss, but NASA at the time deliberately sacrificed technical performance for the benefit of security, locating the crucial ground terminal well within continental United States soil.

11 Ken Atchison, "NASA to Change Tracking and Data Acquisition Operations," News Release Number 79-172, 7 December 1979, NASA Headquarters.

12 Carolynne White, GSFC News Release 89-2, 13 January 1989, Folder Number 8818, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
13 William C. Schneider, Statement Before the Subcommittee on Science, Technology and Space of the Committee on Commerce, Science and Transportation of the U.S. Senate, 28 February 1979, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
14 Linda Neuman Ezell, NASA Historical Data Book, Volume III: Programs and Projects, 1969–1978, p. 424 (NASA SP-4012, Washington, DC, 1988), p. 424.
15 Edmond C. Buckley to George E. Mueller et al., "Data Relay Satellite System Requirements and Interface Panel," 1 September 1967; and Gerald M. Truszynski to John F. Clark, "Data Relay Satellite System Studies," 3 December 1968.
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21 "Harris Antennas and Hardware for White Sands," Harris Fact Sheet #1, Harris Corporation, Melbourne, Florida, Folder 8781, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
22 Judy A. Rumerman, *NASA Historical Data Book Volume VI 1979-1988* (National Aeronautics and Space Administration Special Publication-4012, 2000), p. 314.
23 Robert Spearing interview.
24 Donald H. Martin, "Communications Satellites 1958–1992," The Aerospace Corporation, El Segundo, California, 1991, pp. 186–189. In July 1983, Fairchild Industries, Incorporated of Germantown, Maryland and the Atlanta, Georgia based Continental Telecom, Incorporated, announced that they had become owners of Space Communications by completing their purchase of Western Union's half-interest in Spacecom.

Western Union's share for liquidating its 50 percent interest amounted to $29 million. Prior to the transaction, Fairchild and Continental Telecom each owned 25 percent of Spacecom. The agreement followed a change in the contract giving NASA total use of TDRSS. Originally, a portion of the satellite network capacity was to have been reserved, available for commercial use by Western Union. The three members of the former partnership received $35 million from NASA under the terms of the buyout.

25 Aller, Robert O., "TDRSS Lessons Learned. Presentation to NASA Management, Office of Management and Budget, and Congress," Annapolis, August 18019, 1989.

26 See Note 23.

27 Although he thought there must have been a better word, Charles Force, then Deputy Project Manager for TDRSS, first used the term "segment" to describe both the space and ground components of TDRSS, realizing neither the spacecraft nor the ground station people would ever accept the term "sub-system" to describe those parts of the system. As used here to describe space and ground components of satellite systems, "segment" is a term that has since come into common use.

28 See Note 9.

29 See Note 23.

30 Harold G. Kimball to Marvin Skeeth, Electromagnetic Compatibility Analysis Center, Technical Note 2077, 15 July 1978, Folder 8781, NASA Historical Reference Collection, NASA Headquarters, Washington, DC. Electromagnetic compatibility (or more precisely, interference) was a serious issue. In 1991, for instance, TDRS-3 interfered with two major U.S. commercial, communication satellites, the result of which was disruption of cable television services across the country. On October 22, as Goddard was repositioning TDRS-3, it came near the Hughes Galaxy 1 communications satellite disturbing half of its C-band transponders. The next day, users of GE Americom's Satcom 1R experienced similar trouble. The result was hours of intermittent noise, snow and ghost images for those watching CNN, ESPN, TNT and several movie channels. Hughes official said NASA had not told industry that it was moving the TDRS spacecraft and the company had to call the North American Aerospace Defense Command (NORAD) to find out what caused the snafu. Associate Administrator Charles T. Force said at the time that Goddard engineers suspected a hardware problem on the TDRS which resulted in errant transmissions. (Aviation Week and Space Technology, 4 November 1991, p. 19.)

31 Joe McRoberts, Western Union TDRSS Contract Modified, NASA News Release 79-19, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

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33 NASA's Tracking and Data Relay Satellite System, NASA Press Release 82-186, December 1982, NASA Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.
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35 Ibid.
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39 Space Network User's Guide (SNUG), 450-SNUG, Revision 8, NASA Goddard Space Flight Center, Greenbelt, Maryland, June 2002.
40 See Note 33.
41 Ibid.
42 Ibid.
43 "Tracking and Data Relay Satellite Description: Tracking, Telemetry & Command System," *http://msp.gsfc.nasa.gov/tdrss/ttc.html* (accessed 25 January 2006). As somewhat of a footnote, there is actually one other communication system. TDRS 1 through 6 actually hosted a Ku-band commercial payload which was never activated, and a commercial C-band antenna and payload package which was then operated by Western Union dedicated to their Westar satellite program.
44 Dennis R. Jenkins, "Space Shuttle: The History of the National Space Transportation System" (Ian Allan Publishing, Ltd., 2001), p. 270.
45 A Ku-band system provides a much higher gain, stronger RF signal with a smaller antenna than is possible with a S-band system.
46 *National Space Transportation System Reference Manual* (NASA Kennedy Space Center, 1988).
47 Alfred Rosenthal, *Vital Links* (NASA Goddard Space Flight Center, 1983), p. 210.
48 See Note 46.
49 "Pioneer NASA Spacecraft Celebrates 20 Years of Service," NASA New Release 03-130, 03 April 2003, *http://www.nasa.gov/home/hqnews/2003/apr/HP_news_03130.html* (accessed 10 March 2006).
50 Ibid.
51 Transcript from the Operational Recorder recovered from onboard the vehicle showed that at least some of the crew was aware something

was wrong immediately before the vehicle broke up. Pilot Mike Smith uttered an ominous "Uh oh," the last thing recorded just before loss of all data. Wreckage eventually retrieved from the bottom of the Atlantic also showed evidence that the crew (at least some) may have survived the initial breakup of *Challenger* as some switches activating each crew member's emergency personal oxygen kit had been manually toggled. Today, the remains of the Shuttle *Challenger* are permanently entombed inside a sealed Minuteman missile silo at Complex 31 on Cape Canaveral Air Force Station.

52 William P. Rogers, Chairman, "Presidential Commission on the Space Shuttle Challenger Accident, Final Report," 6 June 1986.

53 Jenkins, pp. 291–296.

54 After the loss of *Challenger*, the issue of crew escape systems was reexamined. A telescoping slide-pole concept was selected. The method, useful only below velocities of 370 kilometers (230 miles) per hour and altitudes below 9,150 meters (30,000 feet) during a controlled glide, had a 3 meter (9.8 foot) long curved aluminum pole which could be extended from the Orbiter's side hatch. During an evacuation, crew members would attach themselves with special parachute harnesses and slide down the pole, directing them underneath the Shuttle's left wing. A crew of seven could theoretically evacuate the Orbiter in 90 seconds. This would be the last resort prior to ditching the vehicle in a catastrophic emergency.

55 SNUG, p. 2–6.

56 Force interview.

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61 See Note 22.

62 Ground Network Users Guide (GNUG).

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65 Ibid.

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73 See Note 68.
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or by capturing them in the Van Allen Belts. Of these belts, discovered by the first U.S. satellite, Explorer 1 in 1958, there are two, one closer and the other farther away. Both surround Earth like a doughnut. However, at a certain location over the South Atlantic Ocean between Brazil and Africa, the shielding effect of the magnetosphere is not quite spherical but shows a "pothole" or a dip, which scientists explain as a result of the offset of the center of the magnetic field from the geographical center of Earth (by some 450 kilometers or 280 miles), as well as the displacement between the magnetic and geographic poles of Earth. For low-Earth orbiting satellites inclined between 35 and 60° with respect to the Equator, this oddity, called the South Atlantic Anomaly, becomes important since spacecraft in those orbits periodically pass through that zone of reduced natural shielding and thus spend a few minutes during each orbit exposed to much higher cosmic particle flux. Thus, vehicles in such orbits require higher shielding for the crew. It is also of concern in the design of space-hardened electronics which are degraded faster by higher particle fluxes. The design of the International Space Station, for instance, takes this effect into account.

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